

# Forage Yield and Nutrient Uptake of Warm-Season Annual Grasses in a Swine Effluent Spray Field

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## ABSTRACT

Five warm-season annual grasses were compared for dry matter (DM) yield and nutrient uptake alongside bermudagrass [*Cynodon dactylon* (L.) Pers.] on a Brooksville silty clay (fine, montmorillonitic, thermic Aquic Chromuderts) in a field that had swine (*Sus scrofa*) effluent applied through a center pivot sprinkler system. Annuals were browntop millet [*Panicum ramosum* (L.) Stapf in Prain], pearl millet [*Pennisetum glaucum* (L.) R. Br.], sudangrass [*Sorghum bicolor* (L.) Moench], sorghum-sudan, [*Sorghum bicolor* (L.) Moench], and crabgrass [*Digitaria sanguinalis* (L.) Scop.]. Grasses were tested in 3 yr (1999–2001), but results in 2000 were incomplete due to poor growing conditions. In 1999 (establishment year for bermudagrass) sorghum-sudan had the highest DM yield (18.9 Mg ha<sup>-1</sup>) and P uptake (50.3 kg ha<sup>-1</sup>). In 2001, sorghum-sudan DM yield (20.6 Mg ha<sup>-1</sup>) and P uptake (56.3 kg ha<sup>-1</sup>) were equivalent to established bermudagrass (21.3 Mg ha<sup>-1</sup> and 56.1 kg ha<sup>-1</sup>, respectively). In 2001 sudangrass and pearl millet DM yields (17.4 and 15.7 Mg ha<sup>-1</sup>, respectively) were equal to and lower than sorghum-sudan, but P uptake of pearl millet (49.5 kg ha<sup>-1</sup>) did not differ from sorghum-sudan, due to the high P concentration (3.2 g kg<sup>-1</sup>) in pearl millet. Browntop millet and crabgrass DM yields and P uptake were less than those of sorghum-sudan in both years. Sorghum-sudan and pearl millet were higher in DM yield and P uptake than the other annuals in both years, equal to established bermudagrass, and therefore should be the most useful in nutrient management hay systems in the southeastern USA.

SINCE THE 1980s, swine production in the USA has shifted away from large numbers of independent growers toward fewer and larger farm operations and contract growers (Welsh and Hubbell, 1999). This industrial shift resulted in concentrating larger numbers of hogs per hectare and spreading their manure as fertilizer over smaller areas. The value of swine effluent as fertilizer is in its nutrient content, especially N. Even with good utilization of N, however, other manure nutrients, especially P, can build up in manured soils. Accumulation of excess P to the point of runoff can pose an environmental risk. The need for better utilization of N and P has focused research toward nutrient uptake by forages (Sims and Wolf, 1994).

In the lower South, perennial grasses receive more effluent than other forages. Burns et al. (1985) reported

that 'Coastal' hybrid bermudagrass receiving 670 kg N ha<sup>-1</sup> and 153 kg P ha<sup>-1</sup> from swine effluent removed an average of 382 kg N ha<sup>-1</sup> yr<sup>-1</sup> and 43 kg P ha<sup>-1</sup> yr<sup>-1</sup>. Adeli and Varco (2001) found that 'Alicia' bermudagrass responded to increasing levels of effluent by increased DM yield and P uptake, up to a fertilizer N equivalent of 448 kg ha<sup>-1</sup>, but the efficiency of nutrient recovery in forage as a percentage of nutrient applied in effluent declined at greater rates of effluent fertilization. This was consistent with a similar finding by Liu et al. (1997) for 'Russell' bermudagrass. Maccoon et al. (2002) also reported a threshold on forage growth, with relatively little effect from dairy manure N rates above 450 kg ha<sup>-1</sup>.

Higher plants require N and P in ratios between 6:1 and 10:1, respectively (Sharpley and Halvorson, 1994). Adeli and Varco (2001) found the N/P ratio of swine lagoon effluent, collected from 1994 through 1996 (on the same farm used in the present study), averaged 6.75:1. They also reported N/P ratios in harvested bermudagrass from 6.8 without effluent to 11 with the highest level of effluent fertilization, and concluded that soil P accumulation would be expected for grass uptake ratios  $\geq 10$ .

Nutrient uptake is not entirely a function of herbage yield but varies with cultivar, weather, soil, and management (Robinson, 1996). Brink et al. (2003) found that because of differences in nutrient concentration, P uptake per hectare by common bermudagrass was equal to or greater than that of several hybrids, despite lower annual DM yield. Annual forage grasses may be lower yielding and less responsive to applied nutrients, but have higher nutrient concentrations than perennial grasses (Robinson, 1996). Uptake of P by temperate species such as ryegrass (*Lolium multiflorum* Lam.), grown as cool-season annuals, may exceed that of bermudagrass because the typical N/P ratio in ryegrass may be lower than that in bermudagrass (6.2:1 vs. 10:1; Edwards, 1996). In a single spring harvest hay system, P, Cu, and Zn uptake by annual ryegrass was greater than that by small grains and annual legumes typically grown in the Southeast (Brink et al., 2001).

The major limitation of cool-season (temperate) species, however, is that their growth occurs in late fall, winter, and early spring when weather and field conditions often preclude hay harvest. The objective of this study was to determine and compare the DM yield and nutrient uptake of five warm-season annual forage grasses and perennial common bermudagrass in the high

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**Abbreviations:** BMG, bermudagrass; BTM, browntop millet; CEC, cation exchange capacity; CRB, crabgrass; DM, dry matter; OM, organic matter; PRL, pearl millet; SSH, sorghum-sudan hybrid; SUD, sudangrass.

**Table 1.** Soil test nutrient levels before growing seasons in 1999 and 2001.

Sample depth	pH	OM†	CEC‡	P	K	Ca	Mg	S	Zn
cm		g kg <sup>-1</sup>	cmol. kg <sup>-1</sup>	mg kg <sup>-1</sup>					
				1999					
0–2.5	7.7	32.7	29.39	271	1068	4886	268	235	3.45
2.5–5.0	8.0	28.9	27.47	34	485	4943	183	207	1.20
5.0–10	8.1	24.5	27.74	25	396	5128	131	176	0.85
10–20	8.2	22.4	28.45	8	196	5468	75	161	1.13
				2001					
0–2.5	7.9	67.9	30.50	400	1178	4909	352	489	2.63
2.5–5.0	8.2	36.2	31.71	122	872	5425	281	261	0.90
5.0–10	8.2	33.4	31.98	45	647	5728	201	240	0.83
10–20	8.2	29.2	32.16	15	379	6070	101	203	0.43

† OM, organic matter.

‡ CEC, cation exchange capacity.

nutrient soil of a swine effluent spray field. The goal was to develop new information on these warm-season species in this high nutrient environment. The information would be useful in refining species recommendations for forage rotations under swine effluent irrigation in the southern USA.

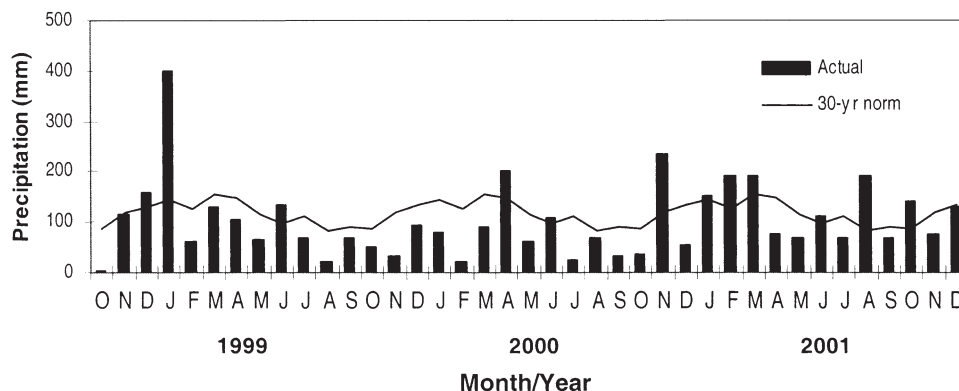
## MATERIALS AND METHODS

The 3-yr experiment was conducted in 1999, 2000, and 2001 in a spray field under center pivot irrigation with swine effluent from two anaerobic lagoons. Plots were on a Brooksville silty clay with 2 to 3% slope within the Blackland Prairie major land resource area. The spray field was located between and received effluent from two commercial swine production facilities near Crawford in Lowndes County, Mississippi. The field had an 8-yr history of effluent applications and produced summer hay from a mixed grass stand predominated by johnsongrass [*Sorghum halipense* (L.) Pers.] and dallisgrass (*Paspalum dilatatum* Poir.) (McLaughlin et al., 2004). Soil test nutrients, pH, and other soil properties are listed in Table 1.

Treatments consisted of five warm-season annual grass species and were arranged in a randomized complete block design with three replicates. The grasses were 'Common' browntop millet, 'Tifleaf 3' pearl millet, 'Monarch V' sudangrass, 'Sweet Sunny Sue' sorghum-sudan, and 'Red River' crabgrass. Common bermudagrass was included as a reference comprising a sixth treatment. Grasses were grown in 2 by 5 m plots surrounded by 2-m fallow alleys. Annuals were seeded during the third week of May in each year. Seed was planted in rows drilled 18 cm apart using a small plot cone seeder (ALMACO, Nevada, IA). The plot area was prepared for planting in the first year by application of glyphosate herbicide [isopropylam-

ine salt of N-(phosphonomethyl)glycine] at the recommended rate in early April, followed by light disking 2 wk later. A second application of glyphosate was made 1 wk before planting. In subsequent years, plots were not tilled but received one application of glyphosate 2 wk before planting followed by close mowing to remove plant residues.

Grasses were seeded at recommended rates: 22.4 kg of seed ha<sup>-1</sup> for browntop millet, pearl millet, sudangrass, and sorghum-sudan; and 16.8 kg ha<sup>-1</sup> for crabgrass. Seed of pearl and browntop millet and sorghum-sudan was supplied by Kaufman Seeds, Ashdown, AR; sudangrass by Cal-West Seeds, Woodland, CA; and crabgrass by Elstel Farm and Seeds, Ardmore, OK. Common bermudagrass plots were established from 8-wk-old rooted transplants set in a grid pattern (12 plants m<sup>-2</sup>) during the first week of May 1999. Transplants were started in a greenhouse using stolon cuttings obtained from G.E. Brink, USDA-ARS, Mississippi State, MS. Although effluent applications were at the discretion of the commercial farm manager and were not monitored or controlled in this experiment, estimates of the amounts applied were available from results of other studies conducted on the same farm during this time. Nutrient analyses of effluent from the farm lagoons have been published (Adeli and Varco, 2001). Before the present study, effluent applications had been made to the spray field for 8 yr and nutrient concentrations in the effluent had been monitored for 6 yr (Adeli and Varco, 2001; Brink et al., 2003). Effluent applied to the spray field had been monitored for 3 yr before the present study and averaged 371, 61, 629, 46, 0.61, 2.12, 30, 0.27, and 0.75 kg ha<sup>-1</sup> yr<sup>-1</sup> of N, P, K, Ca, Cu, Fe, Mg, Mn, and Zn, respectively (Brink et al., 2003), over the 3-yr period. Below-normal rainfall occurred in spring 1999 (Fig. 1) but above-normal rainfall and weekly effluent applications (0.3 to 0.6 ha cm application<sup>-1</sup>, one to



**Fig. 1.** Monthly precipitation totals at the experimental site near Crawford, MS from October 1998 through December 2001 (source: [www.srh.noaa.gov/jan/climate/climate\\_crawford5w.htm](http://www.srh.noaa.gov/jan/climate/climate_crawford5w.htm); verified 14 July 2004).

two times per week) in June, provided adequate soil moisture for successful establishment of all grasses. Below-normal rainfall during the fall and winter of 1999 and early spring of 2000 contributed to low water levels in the effluent lagoons and resulted in fewer effluent applications during the 2000 growing season. Rainfall during the May through September growing season totaled 293 mm in 2000, or 59% of the 30-yr average precipitation during these 5 mo. Drought and reduction in effluent irrigation caused stand failures of pearl millet, sorghum-sudan, and sudangrass in 2000, but bermudagrass, browntop millet, and crabgrass produced stands and were harvested. Regular effluent applications (0.3–0.6 ha cm application<sup>-1</sup>, one to three times per week from April through September) resumed in 2001. May through September precipitation in 2001 was near normal, representing 102% of the 30-yr average rainfall. Nutrient analyses of soil in the plot area before and during the study are shown in Table 1. Soil test P levels were extremely high, especially in the top 2.5 cm (Table 1).

Grasses were managed for hay production according to individual species requirements. Sudan, sorghum-sudan, and millet were harvested at a cutting height of 20 cm when plants were 0.8 to 1.8 m tall, crabgrass was harvested in the boot stage at a cutting height of 10 cm, and bermudagrass was harvested at a cutting height of 2.5 cm at 6- to 8-wk intervals. Plots were harvested by using a sicklebar mower to cut a 1- by 5-m strip down the center of each plot. Fresh weight yields were recorded and 1-kg samples were dried in a forced-air oven at 65°C for 72 h to determine DM biomass. Dried samples were ground to pass a 1-mm screen and 50-g subsamples were stored at room temperature in sealed amber-color plastic bottles for subsequent nutrient analysis. Total N concentration was determined by the macro-Kjeldahl procedure (Bremner, 1996). Forage samples were prepared for determination of Ca, Cu, Fe, K, Mg, Mn, P, and Zn concentrations by ashing a 0.8-g ground subsample in a ceramic crucible at 500°C for 4 h, dissolving the ash in acid (1.0 mL of 6 M HCl) for 1 h followed by addition of 40 mL of double acid (0.0125 M H<sub>2</sub>SO<sub>4</sub> and 0.05 M HCl) for an additional hour, then filtering the extract through Whatman no. 1 filter paper. Nutrient concentrations of acid extracts were determined spectrophotometrically using an inductively coupled argon plasma emission spectrophotometer (Brink et al., 2001). Nutrient uptake was calculated as the product of the nutrient concentration and dry matter yield for each plot and harvest.

Dry matter yield and nutrient uptake data for each treatment were summed across harvests for each growing season and subjected to analysis of variance (ANOVA) (SAS Inst., 1990). Means were compared by Fisher's protected least significant difference (LSD). Unless noted otherwise, the 0.05 level of probability was used to separate differences. Analysis showed a year  $\times$  treatment interaction for DM yield ( $P = 0.0001$ ) and uptake of all nutrients ( $P = 0.0001$  for N, P, Ca,

K, Mg, Mn, and Zn;  $P = 0.0229$  for Cu) except Fe ( $P = 0.1850$ ); therefore, means for these variables were compared among grasses within years and among years within grasses. Comparisons of Fe uptake by the six grasses were made using only data from 1999 and 2001. PROC CORR, a SAS procedure for correlation analysis, was used to determine if linear correlations existed among selected nutrients (both concentrations and uptake) quantified in the different grass species.

## RESULTS AND DISCUSSION

### Dry Matter Yield

Sorghum-sudan had the greatest DM yield of the annual grasses in 1999 and also exceeded the DM yield of bermudagrass, but in 2001 sorghum-sudan and bermudagrass DM yields were similar and greater than yields of the other grasses (Table 2). During its establishment year, bermudagrass had the lowest DM of all six grasses. The DM production of bermudagrass, however, approximately doubled each year following establishment (Table 2). Yields of sudangrass and pearl millet in 2001, although lower than DM yields of bermudagrass and sorghum-sudan, were approximately double those of browntop millet and crabgrass (Table 2).

Dry matter production by common bermudagrass in this study approached that reported for hybrid Coastal bermudagrass (22.4 Mg ha<sup>-1</sup>) (Follett and Wilkinson, 1985) and was within the range reported for bermudagrass fertilized with beef cattle feedyard effluent (Miller et al., 2001). Dry matter yield of sorghum-sudan in the present study was also near or greater than reported values for this forage (17.92 Mg ha<sup>-1</sup>, Follett and Wilkinson, 1985; 2.8–7.4 Mg ha<sup>-1</sup>, Fontaneli et al., 2001). Dry weight yields of Tifleaf 3 pearl millet in the present study were slightly greater than those reported for Tifleaf 2 by Hanna (2000) (11.5–12.7 Mg ha<sup>-1</sup>) and nearly double the range reported by Fontaneli et al. (2001) for Tifleaf 2 and other cultivars (4.8–8.0 Mg ha<sup>-1</sup>).

### Nitrogen and Phosphorus Uptake

Uptake of N and P by the six grasses is summarized in Table 2. Uptake of N and P paralleled the DM pattern, with sorghum-sudan highest in 1999 and bermudagrass lowest. In 2001, sorghum-sudan uptake of N and P was not significantly different from that of bermudagrass. These results are consistent with published values for N and P uptake at 560 and 68.3 kg ha<sup>-1</sup>, respec-

**Table 2. Dry matter yield and N and P uptake of warm-season grasses fertilized with swine lagoon effluent.**

Grass	DM				N				P			
	1999	2000	2001	LSD(0.05)	1999	2000	2001	LSD(0.05)	1999	2000	2001	LSD(0.05)
	Mg ha <sup>-1</sup>								kg ha <sup>-1</sup>			
Bermudagrass	5.6c†	10.6a	21.3a	5.9	88.0d	202.9a	448.0a	127.7	15.6c	25.0a	56.1a	16.7
Browntop millet	10.4b	4.3b	8.6d	1.3	153.7bc	130.5a	210.2c	29.6	24.0b	9.1b	24.1c	5.6
Crabgrass	10.0b	1.6b	8.1d	2.7	145.1c	33.0b	180.2c	43.2	26.2b	2.6b	21.3c	6.6
Pearl millet	12.5b	ND‡	15.7c	0.7	189.7b	ND	433.0a	73.4	31.1b	ND	49.5ab	1.0
Sorghum-sudan	17.3a	ND	20.6ab	NS§	250.8a	ND	393.3ab	NS	44.3a	ND	56.3a	NS
Sudangrass	13.2ab	ND	17.4bc	NS	168.3bc	ND	349.2b	NS	28.6b	ND	43.4b	NS
LSD 0.05	4.3	3.4	3.4		39.8	76.8	63.2		7.8	9.1	8.7	

† Means followed by different letters within columns were significantly different by Fisher's protected LSD ( $P \leq 0.05$ ).

‡ ND, no data.

§ NS, nonsignificant.



**Table 3. Macronutrient uptake of warm-season grasses fertilized with swine lagoon effluent.**

Grass	Ca				K				Mg			
	1999	2000	2001	LSD(0.05)	1999	2000	2001	LSD(0.05)	1999	2000	2001	LSD(0.05)
	kg ha <sup>-1</sup>											
Bermudagrass	33.0d†	57.9a	127.9a	51.4	172.3c	203.2a	500.4b	147.4	10.0c	9.7	28.6a	11.1
Browntop millet	55.8bc	30.2b	62.7cd	13.7	318.7b	190.7a	331.9c	33.4	21.7ab	7.3	21.5b	2.8
Crabgrass	46.7c	10.5b	41.8d	12.5	313.3b	61.4b	320.9c	92.1	17.1b	3.5	25.1ab	7.7
Pearl millet	66.2b	ND‡	94.1b	NS§	387.3ab	ND	707.7a	154.6	22.8a	ND	21.2b	NS
Sorghum-sudan	95.3a	ND	87.8bc	NS	460.4a	ND	589.0b	NS	23.3a	ND	25.2ab	NS
Sudangrass	67.4b	ND	72.9bc	NS	354.8b	ND	545.1b	NS	18.5ab	ND	20.2b	NS
LSD 0.05	13.0	26.5	25.7		91.1	81.3	102.2		5.6	NS	6.4	

† Means followed by different letters within columns were significantly different by Fisher's protected LSD ( $P \leq 0.05$ ).

‡ ND, no data.

§ NS, nonsignificant.

tively, in Coastal bermudagrass, and 364 and 61 kg ha<sup>-1</sup>, respectively, in sorghum-sudan (Follett and Wilkinson, 1985). Miller et al. (2001) reported P uptake by bermudagrass of 41 and 112 kg ha<sup>-1</sup> on two soils fertilized with high rates of beef (*Bos* sp.) cattle feedyard effluent (500 kg N ha<sup>-1</sup> yr<sup>-1</sup> in 19.4-cm effluent). Pearl millet, although lower in DM than sorghum-sudan and bermudagrass, took up comparable amounts of N and P in 2001, owing to significantly higher mean concentrations of N (29 g kg<sup>-1</sup>) and P (3.2 g kg<sup>-1</sup>) than the other grasses. Nutrient concentrations in bermudagrass were 21 g kg<sup>-1</sup> for N and 2.6 g kg<sup>-1</sup> for P. Concentrations in sorghum-sudan were 19 g kg<sup>-1</sup> for N and 2.7 g kg<sup>-1</sup> for P. Calculations from crude protein data reported by Fontaneli et al. (2001) indicated N concentrations of sorghum-sudan at 21 to 24 g kg<sup>-1</sup> and pearl millet at 22.6 to 25.6 g kg<sup>-1</sup>.

Ratios of N/P for the six grasses in 2001 ranged from 7.0 for sorghum-sudan to 8.7 for browntop and pearl millets, with bermudagrass and sudangrass at 8.0 and crabgrass at 8.5. These N/P ratios were below the value of 10.0 projected by Adeli and Varco (2001) as the threshold for build up of excess P in soils fertilized with swine effluent. The rate of soil P accumulation in this spray field under johnsongrass haying has been estimated at 44.5 kg ha<sup>-1</sup> yr<sup>-1</sup> (McLaughlin et al., 2004) based on a mean annual P application rate of 61 kg ha<sup>-1</sup> (Brink et al., 2003) and a P recovery rate of 27% (Adeli and Varco, 2001). The actual P recovery rates for grasses in the present study were not determined, since it was not feasible to include additional plots (without effluent applications) for measurement of soil-supplied nutrient uptake levels. Nevertheless, the P uptake measured here (56 kg ha<sup>-1</sup> for bermudagrass and sorghum-sudan in 2001) is 92% of the estimated annual amount applied

as effluent. Converting the haying system in the spray field to bermudagrass or sorghum-sudan would improve the P management. Additional P removal, such as by overseeding the bermudagrass with a winter annual forage harvested as spring hay (McLaughlin et al., 2001; Rowe and Fairbrother, 2003) would further improve the P management.

### Uptake of Other Macronutrients

Uptake of the macronutrients Ca, K, and Mg by the six grasses is shown in Table 3 and followed a similar pattern as the responses of DM yield and N and P uptake. Sorghum-sudan uptake of Ca, K, and Mg was generally greater than other grasses in 1999, but there were no differences in uptake between sorghum-sudan and pearl millet for K or between sorghum-sudan, sudan, pearl millet, and browntop millet for Mg. As expected, in 1999 uptake of these macronutrients by the annual grasses exceeded that of bermudagrass in its establishment year. In 2001, consistent with its increased DM yield, bermudagrass had greater uptake of Ca than annual species, but uptake of Mg was not significantly different from that of crabgrass and sorghum-sudan. Similar uptake of Mg by bermudagrass and sorghum-sudan in 2001 was due to their similar DM yields (Table 2) and Mg concentrations (1.3 and 1.2 g kg<sup>-1</sup>, respectively). Increased uptake of Mg by crabgrass in 2001, despite lower DM yield, was due to a significantly higher Mg concentration (3.1 g kg<sup>-1</sup>). In 2001, K uptake by sorghum-sudan and bermudagrass were similar but both were less than that of pearl millet, owing to a significantly higher concentration of K in pearl millet

**Table 4. Micronutrient uptake of warm-season grasses fertilized with swine lagoon effluent.**

Grass	Cu				Mn				Zn			
	1999	2000	2001	LSD(0.05)	1999	2000	2001	LSD(0.05)	1999	2000	2001	LSD(0.05)
	g ha <sup>-1</sup>											
Bermudagrass	33.9b†	52.5a	165.2b	49.6	181.8c	209.7a	563.3a	218.1	88.7c	244.1a	474.1a	121.2
Browntop millet	63.1b	52.0a	110.8c	13.8	283.0bc	83.6b	200.4c	58.5	159.5b	77.1b	146.3d	36.2
Crabgrass	65.8b	16.5b	97.2c	23.5	269.0bc	24.9b	198.3c	50.0	174.5b	31.7b	163.3d	19.9
Pearl millet	82.5b	ND‡	153.1b	35.3	347.1b	ND	342.8bc	NS	201.0b	ND	282.2c	NS
Sorghum-sudan	192.4a	ND	219.4a	NS§	524.5a	ND	400.5b	NS	348.9a	ND	336.8b	NS
Sudangrass	85.7b	ND	175.1b	NS	345.2b	ND	367.0b	NS	199.6b	ND	276.5c	NS
LSD 0.05	63.4	23.1	34.7		107.8	108.1	150.0		64.1	79.5	52.3	

† Means followed by different letters within columns were significantly different by Fisher's protected LSD ( $P \leq 0.05$ ).

‡ ND, no data.

§ NS, nonsignificant.

**Table 5. Mean annual Fe uptake of warm-season grasses fertilized with swine lagoon effluent in 1999 and 2001.**

Grass	Fe kg ha <sup>-1</sup>
Bermudagrass	2.4ab†
Browntop millet	1.7b
Crabgrass	1.8b
Pearl millet	3.3ab
Sorghum–sudan	3.7a
Sudangrass	3.8a
LSD 0.05	1.7

† Means followed by different letters were significantly different by Fisher's protected LSD ( $P \leq 0.05$ ).

(45.9 g kg<sup>-1</sup>) compared with sorghum–sudan (27.9 g kg<sup>-1</sup>) and bermudagrass (22.4 g kg<sup>-1</sup>).

### Uptake of Micronutrients and Iron

Uptake of the micronutrients Cu, Mn, and Zn by the six grasses is shown in Table 4. Sorghum–sudan had the highest uptake of these nutrients in 1999. In 2001 sorghum–sudan was also highest in copper uptake, but was lower than bermudagrass for Mn and Zn uptake. Copper concentrations were similar in sorghum–sudan and sudangrass in 2001 (10.3 and 10.2 mg kg<sup>-1</sup>, respectively) and slightly higher than that of bermudagrass (6.9 mg kg<sup>-1</sup>). Bermudagrass had greater uptake of Mn in 2001 than sorghum–sudan despite similar DM yields because the Mn concentration in bermudagrass (26.8 mg kg<sup>-1</sup>) was greater than that in sorghum–sudan (19.2 mg kg<sup>-1</sup>). Bermudagrass also had greater uptake of Zn in 2001 compared with sorghum–sudan, and both were higher than the other grasses. The highest uptake of Zn was by bermudagrass in 2001 and was due to a combination of the highest DM (Table 2) and the highest concentration (22.6 mg kg<sup>-1</sup>).

Uptake of Fe was independent of year  $\times$  species effects, so data from 1999 and 2001 were combined for grass means comparisons (Table 5). Iron uptake by sudangrass and sorghum–sudan, although numerically higher, was not statistically higher than that by pearl millet and bermudagrass. Uptake of Fe by sudangrass and sorghum–sudan was higher than that by browntop millet and crabgrass. Concentrations of Fe did not differ among the six grasses (mean = 229.6 mg kg<sup>-1</sup>); therefore, differences in uptake were related to DM production.

### Correlations of Nutrient Concentrations and Uptake

Pederson et al. (2002) reported that N, P, Cu, and Zn concentrations were highly correlated for all above-ground parts of several temperate forages grown as cool-season annuals in Mississippi. The forages they tested included annual ryegrass, three cereal grasses, and 12 legumes. They suggested that increasing manure or commercial fertilizer N could increase N uptake and improve P, Cu, and Zn concentrations and uptake. All possible correlations of nutrient concentration and uptake by these four nutrients were explored within grasses and years in the present study. Correlations of nutrient concentration means for the six grasses during 2 yr of the present study are shown in Table 6, correlations of nutrient uptake means in Table 7, and correlations between N concentration means and nutrient uptake means in Table 8.

Significant positive correlations, which were consistent in both years, were observed between N and P concentrations in browntop millet and crabgrass, between N and Cu concentrations in pearl millet, and between P and Cu concentrations in sudangrass (Table

**Table 6. Linear correlation coefficients of N, P, Cu, and Zn concentrations in six warm-season grasses.**

Nutrient conc.		BMG†		BTM		CRB		PRL		SSH		SUD	
		1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001
N	P	0.92**	-0.37	0.81*	0.69*	0.86*	0.90***	0.66	0.50	-0.09	0.77*	0.35	0.82**
N	Cu	0.98***	0.23	0.93**	0.65	0.97**	0.57	0.85*	0.95***	0.11	0.86**	0.57	0.79*
N	Zn	0.81*	-0.67	0.47	-0.17	0.72	0.19	0.80	-0.06	0.18	0.39	0.79*	0.12
P	Cu	0.88*	0.21	0.61	0.30	0.74	0.57	0.32	0.34	0.96***	0.54	0.71*	0.95***
P	Zn	0.71	0.20	0.63	-0.13	0.92*	0.16	0.85*	-0.08	0.95***	0.33	0.75*	0.37
Cu	Zn	0.78	-0.17	0.51	0.32	0.62	0.71*	0.57	0.05	0.96***	0.44	0.64	0.41

\* Significant at the 0.05 probability level.

\*\* Significant at the 0.01 probability level.

\*\*\* Significant at the 0.001 probability level.

† BMG, bermudagrass; BTM, browntop millet; CRB, crabgrass; PRL, pearl millet; SSH, sorghum–sudan hybrid; SUD, sudangrass.

**Table 7. Linear correlation coefficients of N, P, Cu, and Zn uptake in six warm-season grasses.**

Nutrient uptake		BMG†		BTM		CRB		PRL		SSH		SUD	
		1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001
N	P	0.94**	0.89**	0.12	0.97***	-0.09	0.98***	0.10	0.97***	0.88**	0.98***	0.75*	0.98***
N	Cu	0.99***	0.89**	0.51	0.91***	0.63	0.75*	0.58	0.90***	0.76*	0.91***	0.91***	0.89**
N	Zn	0.87*	0.59	0.27	0.64	0.06	0.65	0.67	0.84**	0.84**	0.90***	0.87**	0.93***
P	Cu	0.94**	0.90***	0.55	0.91***	0.39	0.77*	0.48	0.79*	0.82**	0.82**	0.85**	0.90***
P	Zn	0.98***	0.80**	0.84*	0.67*	0.74	0.63	0.63	0.93***	0.92***	0.92***	0.93***	0.97***
Cu	Zn	0.86*	0.83**	0.78	0.86**	0.16	0.84**	0.69	0.56	0.98***	0.83**	0.88**	0.85**

\* Significant at the 0.05 probability level.

\*\* Significant at the 0.01 probability level.

\*\*\* Significant at the 0.001 probability level.

† BMG, bermudagrass; BTM, browntop millet; CRB, crabgrass; PRL, pearl millet; SSH, sorghum–sudan hybrid; SUD, sudangrass.

**Table 8. Linear correlation coefficients of N concentration and N, P, Cu, and Zn uptake in six warm-season grasses.**

Nutrient		BMG†		BTM		CRB		PRL		SSH		SUD	
Conc.	Uptake	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001
N	N	-0.53	0.41	0.45	0.87**	0.78	0.87**	0.71	-0.28	-0.17	0.44	-0.03	0.44
N	P	-0.75	-0.04	-0.82*	0.75*	-0.69	0.91***	-0.63	-0.46	-0.56	0.31	-0.67*	0.35
N	Cu	-0.55	0.12	-0.18	0.65	0.15	0.69*	0.09	0.11	-0.16	0.59	-0.27	0.62
N	Zn	-0.84*	-0.35	-0.54	0.36	-0.37	0.43	0.11	-0.66	-0.28	0.20	-0.40	0.26

\* Significant at the 0.05 probability level.

\*\* Significant at the 0.01 probability level.

\*\*\* Significant at the 0.001 probability level.

† BMG, bermudagrass; BTM, browntop millet; CRB, crabgrass; PRL, pearl millet; SSH, sorghum-sudan hybrid; SUD, sudangrass.

6). Significant positive correlations, which were consistent in both years, were observed for nutrient uptake among all combinations of the four nutrients, except N and Zn, in bermudagrass and for all combinations in sorghum-sudan and sudangrass (Table 7). Significant positive correlations, which were consistent in both years, were also observed between P and Zn uptake in browntop millet (Table 7). No consistent (occurring in both years) correlations were observed for uptake of these four nutrients in crabgrass or pearl millet (Table 7). No consistent positive correlations were found for N concentration with nutrient uptake of N, P, Cu, or Zn in any of the six grasses (Table 8). These results suggested no consistent relationships of nutrient concentrations with uptake applicable to all six warm-season grasses of the present study. The positive correlations in bermudagrass and sorghum-sudan of N uptake with uptake of P and Cu, however, support the results of Pederson et al. (2002) and suggests that increased N uptake corresponds with increased uptake of P and Cu. Providing additional amounts of noneffluent N to these grasses could trigger increased uptake of other nutrients. In the southeastern USA, one option for supplying additional noneffluent N to a bermudagrass hay system is through use of cool-season winter annual legumes, such as berseem clover (*Trifolium alexandrinum* L.), overseeded in the bermudagrass and harvested as spring hay (McLaughlin et al., 2001; Rowe and Fairbrother, 2003).

## CONCLUSIONS

Dry matter yield and P uptake by warm-season annual grasses exceeded that of common bermudagrass during the establishment year for bermudagrass. Established bermudagrass, however, performed as well or better than the annuals. Established bermudagrass has the obvious advantage in nutrient management systems of not requiring annual replanting. Sorghum-sudan and pearl millet, however, are good alternatives for nutrient management in spray fields where nutrient uptake approximating that of established bermudagrass is the goal, but where establishing bermudagrass is either not an option or where lower uptake during the establishment year is too much of a disadvantage in the nutrient management plan. Established bermudagrass generally had higher N and P uptake than the annual grasses. The N/P uptake ratios of all the grasses were favorable for efficient utilization of the N and P in swine lagoon effluent, indicating that these grasses could be used in N and P nutrient management plans on Blackland Prairie soils utilizing

this nutrient resource. Of the warm-season annual grasses compared here for DM yield and P uptake, sorghum-sudan and pearl millet appeared to be the most useful alternatives to common bermudagrass for nutrient management summer hay systems in the southeastern USA.

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